HIGH PERFORMANCE MAGAZINE ACCEPTOR THRESHOLD CRITERIA

James E. Tancreto, NFESC, Port Hueneme, CA
Michael Swisdak, NSWC, White Oak, MD
Javier Malvar, University of California, Davis

26th DDESB Seminar
Doral Resort & Country Club
Miami, Florida
August 16 -18, 1994

ABSTRACT

The Naval Facilities Engineering Service Center is developing a new ordnance storage magazine that will reduce encumbered land and improve operational efficiency. Non propagation walls are used to prevent sympathetic detonation between munitions stored in adjacent cells. Design of the walls, and their mitigation effects, requires sympathetic detonation threshold criteria for acceptor munitions. This paper outlines the procedures being used to develop SD threshold criteria, summarizes test and analysis methods, shows and compares test and analysis data, and provides preliminary SD threshold criteria.

INTRODUCTION

Background

The Naval Facility Engineering Service Center (NFESC), formerly the Naval Civil Engineering Laboratory (NCEL), is developing a new ordnance storage magazine, the High Performance Magazine (HPM). The performance goals of the HPM are to reduce encumbered land and to improve operational efficiency. The concept uses cell and aisle walls to prevent propagation of an explosion to adjacent cells. This significantly reduces the Maximum Credible Event (MCE), reducing encumbered land by at least 80% and reducing safe standoff range by more than 60%. The non-propagation dividing walls also allow storage of non compatible ordnance in the same magazine. A new handling system, using an overhead bridge crane and universal straddle lift, provides improved operational efficiency.

The most important factor in the improved explosives safety performance of the HPM is the reduction of the MCE. For example, the explosive storage capacity of the Type II HPM is 295,000 pounds net explosive weight (NEW) but the MCE is no more than 30,000 pounds NEW in the storage areas and 55,000 pounds NEW in the shipping and receiving area. Inhabited building distance (IBD) is reduced from 3345 ft. to 1330 ft. (60% reduction in safe distance and 84% reduction in encumbered land area).

NFESC has shown that the HPM concept is feasible based on analytical modeling and test

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1994**	2. REPORT TYPE	3. DATES COVERED **00-00-1994 to 00-00-1994**

4. TITLE AND SUBTITLE **High Performance Magazine Acceptor Threshold Criteria**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Facilities Engineering Service Center,1100 23rd Street,Port Hueneme,CA,93043**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM000767. Proceedings of the Twenty-Sixth DoD Explosives Safety Seminar Held in Miami, FL on 16-18 August 1994.

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**18**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

results (small and full scale). In FY93 NFESC conducted two full scale explosive tests of storage cells which demonstrated that the non-propagation cell walls will prevent sympathetic detonation (SD) to MK82 bombs and M107-155mm projectiles. The non-propagation walls were designed using preliminary SD threshold criteria developed from the test and analysis of thick-skin weapons. The tests also verified the procedure for calculating loads, wall response and acceptor response.

In FY94 to FY96, NFESC will conduct additional full-scale explosive tests to certify explosives safety of the HPM prototype design. These tests will be designed to certify compliance with explosives safety regulations for the critical HPM hazard scenarios.

Design of the non-propagation walls requires the development of acceptable sympathetic detonation (SD) threshold criteria. Existing test data is being supplemented with new test and analysis data to develop the SD threshold criteria and to demonstrate the accuracy of the analysis methods.

The Naval Surface Warfare Center is providing support by establishing HPM hazard compatibility groups, defining the critical donors and acceptors, developing threshold peak pressure criteria, and by planning and contracting the SD criteria's tests. SD criteria tests are being conducted at the Energetic Materials and Research and Testing Center (EMRTC), New Mexico Institute of Mining and Technology, Socorro, NM. Full scale certification testing is being conducted at NAWC, China Lake. NFESC is providing acceptor response analysis, assisting with SD test planning, evaluating test results, and developing (with NAWC) the case crushing criteria.

Purpose

The purpose of this paper is to outline the procedures being used to develop SD threshold criteria, summarize test and analysis methods, show and compare test and analysis data, and provide preliminary SD threshold criteria.

Scope

The scope of this paper is limited to the development of acceptor threshold criteria for mechanical mechanisms of sympathetic detonation. Discussion is only as complete as necessary to cover the specific application to the HPM concept. Although the thermal mechanism of sympathetic detonation is included in the HPM design criteria, it is not discussed in this paper but is the subject of the paper " Thermal Loads and Threshold Criteria for Acceptors in the High Performance Magazine" in this seminar by Rodney Harris, NAWC, Weapons Division, China Lake, Ca.

The emphasis of this paper is on the tests and analyses being used to establish SD threshold design criteria. The resulting threshold criteria are preliminary and are based on incomplete testing and analysis. These preliminary criteria do not as yet have the approval of the explosives safety community. Certification tests planned for FY 95 and FY 96 will be used to

develop and propose final criteria.

SYMPATHETIC DETONATION MECHANISMS & CHARACTERISTIC PARAMETERS

The mechanisms of sympathetic detonation are very complicated and are not completely understood. There is no unique set of mechanisms that have been defined and agreed upon. Two mechanisms that are commonly referenced are based on the progression of the chemical reaction: (1) shock to detonation transition (SDT) and (2) deflagration to detonation transition (DDT). To account for unknown mechanisms the term XDT is also used.

Development of a design procedure to prevent SD requires threshold values that can be related to the design environment and acceptor response. These threshold values also must be measurable for validation of analytical methods. The mechanisms that were chosen for use in design are: Direct Shock, Case Crushing, Fragment Impact & Penetration, and Thermal Cookoff.

These mechanisms define a set of overlapping loading and response conditions. They are all related by a threshold explosive pressure environment that, if reached, will create a reaction that will transition to a detonation. Since those pressures cannot be measured directly, other load & response thresholds must be identified and controlled to ensure that the underlying threshold pressure environment is not reached. The assumption is that if safe thresholds are defined and met for each of these overlapping mechanisms, then sympathetic detonation will be prevented. Each of these mechanisms can be characterized by parameters that can be measured and calculated. The safety of a design is evaluated by comparing safe acceptor response (threshold SD values determined by test) with calculated acceptor response (using validated analysis methods).

Direct Shock

The Direct Shock mechanism produces a reaction when the pressure environment, in the explosive, exceeds a threshold value. The main sources of peak pressure in the acceptor munitions are: impact of wall debris, impact between acceptor munitions, impact of acceptor munitions with magazine walls, air shock, and accumulated case crushing. Three criteria were considered for defining the Direct Shock threshold: (1) peak pressure (P, psi); (2) critical energy fluence where the threshold is a function of peak pressure and duration:

$$E = (P_e^2 \tau)/(\rho_o U)$$

Where, E = critical energy fluence, Joules/cm^2

P_e = pressure in the energetic material, kbar
τ = pulse width, s
ρ_o = initial density of the energetic material, gm/cc
U = shock velocity, mm/ s

and (3) a generalized version of the energy fluence criteria based on a proposed method by Soper (Reference 3):

$$\int P^2 dt = \rho_o UE$$

where,

$P = (P_e - P_b)$
$P_b =$ constant pressure for no reaction

Threshold peak pressures for causing ignition in various explosives are given in Table 1 (from References 1 and 2). The Underwater Sensitivity Test (UST) and Modified Gap Test (MGT) differ in the manner in which the load is applied and in the resulting load shape and duration. The longer duration UST test gives lower peak ignition pressures. The critical fluence values, based on a critical energy input to cause ignition, are also given in Table 1.

This pressure environment cannot be measured in live acceptors but it can be calculated. Tests can then be used to demonstrate that no reaction occurs when the calculated value is less than the reaction threshold.

Fragment Impact & Penetration

Fragment impact and penetration is probably the most likely mechanism of sympathetic detonation. Fragments (normally primary fragments from the donor weapon) impact and penetrate the acceptor at sufficient mass and velocity to create extremely high peak pressures (and temperatures) in the explosive fill. The HPM non-propagation walls will be designed to stop all primary fragments. Initial fragment characteristics for sizing an adequate wall were:

fragment size: 1/2" cube
fragment velocity: 8300 fps
fragment material: steel

Wall development tests, using MK82 bombs, showed that primary fragments would not be critical in the wall design. Also, the mass and materials in the non-propagation wall have been chosen to prevent high impact and penetration loads from wall debris. The wall debris is therefore not being classified as a fragment threat. However, the accumulated mass-velocity of the wall debris is the major case crushing load.

TABLE 1. IGNITION THRESHOLDS & CRITICAL FLUENCE

MATERIAL	UST (kbar)	MGT (kbar)	UST/MGT RATIO	UST (a) (kbar)	CRITICAL FLUENCE (J/cm^2)
COMP B-3 (b)	5.5	17.0	0.324		57
60/40 CYCLOTOL (c)	4.7	14.5	0.324		42
H-6 (b)	6.4	18.4	0.348		66
LX-04-1	9.0	25.9	0.347		141
PBX 9404-3	6.0	18.0	0.333		61
PBXN-109	6.1	18.6	0.328		119
PENTOLITE (c)	4.7	12.1	0.388		31
AFX 108E	5.1				75
25/75 CYCLOTOL (b)	6.7				96
PBXC-117	5.1				54
PBXC-121	7.8				
PBXN-103	8.9				149
PBXW-113 II	5.9				88
HBX-1		45.9		15.5	
HBX-3		45.7		15.5	
PBXN-110		26.0		8.8	
PBXN-111		24.0		8.1	
TETRYL		15.2		5.1	

(a) Estimated Value: UST = 0.339*MGT (b) Cast (c) Pressed

TABLE 1. IGNITION THRESHOLDS & CRITICAL FLUENCE

Case Crushing

Case crushing is a mechanism defined by the deformation of the acceptor. It is an indication of the accumulation of loads on the acceptor. In the HPM environment the loads contributing to case crushing are wall impact, acceptor to acceptor impact, acceptor impact with the magazine back wall, and air shock. Peak pressures, developed in the explosive fill during crushing, can be calculated and compared to the peak pressure thresholds for direct shock. Additional loads can also be produced in the explosive due to cracking and friction in the explosive fill or extrusion of the fill through a cracked thick case weapon. Criteria for case crushing must limit the total acceptable loading and deformation (including control of case cracking) of the acceptor. Parameters that can be used to measure and limit case crushing are: (1) D/D, the ratio of the change in diameter to original diameter of the acceptor; (2) the total momentum (or impulse), MV loading the acceptor; and (3) Strain Energy absorbed by the acceptor. It is anticipated that different parameters may be needed to define case crushing

thresholds for thick vs. thin case acceptors.

HPM WORST CASE DONORS & ACCEPTORS

HPM Storage Groups

Eight HPM storage groups (see Table 2) have been defined to organize Navy ordnance into similar hazard categories. The HPM Storage Groups are consistent with the explosive safety storage compatibility groups (SCG) but also use explosive sensitivity, weapon type and construction, and damage mechanisms for obtaining like groups. The HPM concept uses multiple cells within the magazine. Items within each storage group may be stored together within any cell. Groups cannot be mixed within a cell but may be stored in adjacent cells in the same magazine.

TABLE 2. HPM STORAGE GROUPS

HPM STORAGE GROUP	MATERIAL DEFINITION
1	Detonators & Initiating Devices (SCG G)
2	Ammunition Containing Both Explosives & Flammable Liquids or Gels (SCG J)
3	Fireworks, Incendiary, Illuminating, Smoke or Tear Producing Munitions; Ammunition with Initiation Devices (SCG's F&G)
4	Bombs, Projectiles Thick-case Munitions, Fuses, Boosters, Bomb Adaptors
5	Demolition Explosives; very Thin-case Items; Sheet Explosive
6	Cluster bombs; Dispenser Munitions
7	Directed Energy Warhead Munitions
8	Thin-case Items: Most Missiles, Rockets, Underwater Mines & Torpedoes

TABLE 2. HPM STORAGE GROUPS

Worst Case Donors & Acceptors

The design donor is primarily determined by the explosive weight of the MCE and not the characteristics of different munitions. MK82 Bombs have been used in the test program to obtain the desired MCE. Because explosive materials within a single group have similar sensitivities, only the worst case acceptors in each group need to be tested and analyzed to certify that SD has been prevented. The critical acceptors for each group are then used in developing safe criteria. The current list of worst case acceptors is shown in Table 3.

Changes occur periodically as more information is obtained through test and analysis.

TABLE 3. PROPOSED HPM STORAGE GROUP WORST CASE ACCEPTORS

HPM STORAGE GROUP	POTENTIAL WORST CASE ACCEPTORS
1	#8 Blasting Cap
2	HARPOON Cruise Missile TOMAHAWK Cruise Missile
3	106mm Cartridge M61 Hand Grenade
4	MK82/MK83/MK84 Bombs (H-6 Loaded) M107 155mm Projectiles (Comp B Loaded)
5	M118 PETN Demolition Block MK 36 H-6 Demolition Block
6	M483 Series Bomblet Gator Bomblet
7	TOWI/TOWII/TOWIII HELLFIRE
8	MK73 STANDARD Missile w/MK104 Rkt Motor MK107/MK103 Torpedo Warhead MK55 Mine

TABLE 3.
PROPOSED HPM STORAGE GROUP WORST CASE ACCEPTORS

THICK CASE CRITERIA DEVELOPMENT

Data is available for peak pressure thresholds to cause ignition [from Underwater Sensitivity Tests (UST) and Modified Gap Tests (MGT)]. However, there is no data on case crushing thresholds. Flyer plate tests were planned and conducted on MK82 bombs to obtain data on crushing thresholds. DYNA3D analyses were also conducted to predict both internal explosive fill pressure and case deformation. The predicted deformation is directly comparable to test measurements. Peak explosive fill pressures could not be measured, however they were predicted to be less than ignition threshold values. M105-155 mm projectile data, from non propagation wall tests, were also used to develop thick case criteria. This section summarizes the MK82 bomb flyer plate tests.

Test and Analysis

Test Setups. The MK82 bomb with H-6 explosive fill was tested in two types of flyer plate tests. A 4" border was cut from a 4' x 8' x 3" steel plate leaving a flyer plate of 44" x 88" x 3" (3000 lb.). The 4" strip was then lightly welded to the flyer plate. Various thicknesses of

Detasheet, backed by a 1" tamper plate, was detonated behind the flyer plate to obtain different flyer plate velocities. Velocities were measured with 3 pair of piezo pins placed between the flyer plate and acceptor. Test setups and conditions are shown in Figures 1 and 2 and Table 4.

'Crush' tests were conducted to measure case crushing thresholds while limiting the peak pressure at impact (to reduce the possibility of a reaction from peak pressure before large deformations were reached). A 10 inch 'crush pack' of alternating layers of 1" steel plate and 1" polyethylene was placed between the acceptor and flyer plate to reduce the peak pressure loads on the acceptor. The crush pack, acceptor, and backstop were in contact at flyer plate impact. The crush test setup is shown in Figure 1.

'Double Impact' tests, with no crush pack, were conducted to obtain large peak pressures (and deformations) on impact of the flyer plate with the acceptor and at impact of the acceptor with the backstop. The acceptor was not in initially in contact with the backstop. Therefore, a second impact was created when the acceptor contacted the backstop. The double impact test setup is shown in Figures 2.

TABLE 4. MK82 FLYER PLATE TESTS

TEST #	TEST TYPE	BACKSTOP STANDOFF (in)	FLYER PLATE VELOCITY (m/s)
1	Crush	0	91
2	Crush	0	141
3	Crush	0	179
4	Dbl Impact	19.5	149
5	Dbl Impact	12.6	80
6	Dbl Impact	6.75	44

TABLE 4. MK82 FLYER PLATE TESTS

<u>Test Results</u>. Test results are summarized in Table 5. Crush test deformation ranged from slight (Test 1) to severe (Test 3). Moderate deformation (Average D/D = 0.087), in the Test 2 MK82 bomb, is shown in Figure 3. None of the crush tests resulted in any reaction of the acceptor explosive fill. The two double impact tests with the highest flyer plate velocities (80 & 149 m/s) resulted in case rupture and burn of the explosive fill. The rupture appeared to occur at unexpectedly low flyer plate velocities because the flyer plate was not vertical at impact. Therefore, only the base of the flyer plate contacted the MK82 bomb at first impact. This created excessive load concentrations at the base of the MK82. Since this was not

representative of the type of loading that would be created in the HP Magazine, the crush tests (which produced more uniform loading) were used to establish preliminary threshold criteria. However, the double impact tests did show that even with concentrated high peak impact loads (higher than the peak predicted loads in the HP Magazine environment) a detonation reaction did not result.

TABLE 5. MK82 FLYER PLATE TEST RESULTS

TEST #	TEST TYPE	FLYER PLATE VELOCITY (m/s)	REACTION	AVERAGE (a) DEFORMATION ΔD/D (b)
1	Crush	91	None	0 (c)
2	Crush	141	None	0.13
3	Crush	179	None	0.29
4	Impact	149	Burn	N/A
5	Impact	80	Burn	N/A
6	Impact	44	None	0.10

(a) Average of 4 points between base and nose of MK82:
12", 24", 36", & 48" from nose.

(b) $\Delta D/D = (D_{max} - D_{min})/(D_{avg})$

(c) No measurement (small deformations could have been obscured by thermal protection)

TABLE 5. MK82 FLYER PLATE TEST RESULTS

Analysis Models. The finite element code DYNA3D was used to predict the MK82 case deformation and internal H-6 explosive fill pressure. A typical crush test model is shown in Figure 4 at times t = 0 and t = 5 msec. All elements are in contact at time = 0 and the flyer plate has an initial velocity equal to the measured test velocity. At 5 msec the flyer plate has rebounded away from the buffer pack and noticeable deformation is occurring in the buffer pack and back plate.

Figure 5 shows the predicted pressure - time history, in the explosive fill, at a number of critical points. The highest predicted pressure occurs at first impact (near time = 0). It is about 1.5 KBar for Test 2 (see Figure 5). Peak pressure at impact was not considered a likely mechanism for SD in the crush tests. Since the model was designed to predict case deformation, the peak pressure on impact is slightly underestimated (due to relatively large elements in the model). However, the model shown adequately predicts the slower rise time and longer duration pressures that occur during crushing (around 5 - 10 ms in Figure 5). These were always less than the initial impact pressures (about 1.1 KBar in Test 2, Figure 5). The peak predicted pressures, on the flyer plate and backstop sides, of the MK82 are shown in Figure 6. These predicted peak pressures and the pressures during crushing never exceed the

UST threshold for ignition (6.4 KBar per Table 1).

The predicted case deformation (change in diameter = D) is shown at 4 points on the MK82 bomb, vs. the 3 flyer plate test velocities, in Figure 7.

<u>Predicted vs. Measured Response (Crush Tests)</u> The predicted peak explosive fill pressures (see Figure 6) were less than 2 Kbar. It was not possible to measure these pressures in the acceptors. However, since the UST threshold pressure for ignition is 6.4 KBar, the model did correctly predict that ignition would not occur.

The predicted and measured deformations are compared in Figure 7. The DYNA3D predictions were conservative at deformations less than about D/D = 0.25. The locally high measured deformation (for a plate velocity of 180 m/s) probably resulted from non-uniform initial impact by a non-vertical flyer plate (which concentrated loads at the nose of the acceptor).

Preliminary Thick Case SD Threshold Criteria

Preliminary thick case acceptor SD threshold criteria were established for designing the HPM non-propagation walls. They are based on the reported MK82 flyer plate crush test results, DYNA3D predictions, and small and full scale wall tests of the MK82 and M107-155mm projectile (not covered here). Full scale non-propagation wall tests using instrumented inert and live acceptors, conducted in FY93, showed that the overall design criteria were conservative. No reactions occurred and case deformations were no more than 1/2 of the design allowable ($\Delta D/D \leq 0.25$)

(1) The peak pressure in the explosive fill shall be:
- (a) $\leq$ 3 KBars or
- (b) $\leq$ 0.75 * UST value (if known)

(2) The case crushing shall be:

$$\Delta D/D \leq 0.25$$

Full scale non-propagation wall tests, using instrumented inert and live MK82 bomb and M107-155mm projectile acceptors, conducted in FY93, indicated that the preliminary wall design criterion (for loads & wall response as well as SD criteria) is conservative. No reactions occurred and case deformations were no more than 1/2 of the design allowable.

THIN CASE CRITERIA DEVELOPMENT (Progress Report)

Peak pressures to cause ignition [From Underwater Sensitivity Tests (UST) and Modified Gap Tests (MGT)] are available but there is little or no data for establishing case crushing thresholds. Because the thin-case affords little structural resistance, it is expected that the crushing threshold for thin-skin munitions may be based on unit impulse (or momentum) or

unit energy rather than $\Delta D/D$. Flyer plate tests are currently being conducted by EMRTC on Navy underwater mines and torpedoes (data is also being obtained by the US Army ARL, Aberdeen, MD in an Army program testing thin-case TOW warheads and thick case M107-155mm projectiles). Threshold criteria based on $\Delta D/D$, unit impulse, and unit strain energy are being evaluated. Initial results have shown that thin case munitions are more sensitive (than thick case munitions) to ignition, however no detonations have been observed (even at very high strain energy inputs). DYNA3D analyses are being conducted to predict both internal explosive fill pressures and case & explosive fill deformation.

REFERENCES

1. Liddiard, T. P. and Forbes, J. W., "A summary Report of the Modified Gap Test and the Underwater Sensitivity Test," NSWC TR 86-350, 12 March 1987.

2. Lemar, E. R., et. al., "The Analysis of Modified Gap Test Data for Several Selected Insensitive Explosives," NSWC TR 89-290, 1 June 1992.

3. Soper, W.G., "Sympathetic Detonation Analysis Involving Ceramic Buffers: Analysis and Experiment, NSWC TR 89-365, November 1989.

Figure 1. MK82 Bomb Flyer Plate Crush Test Setup

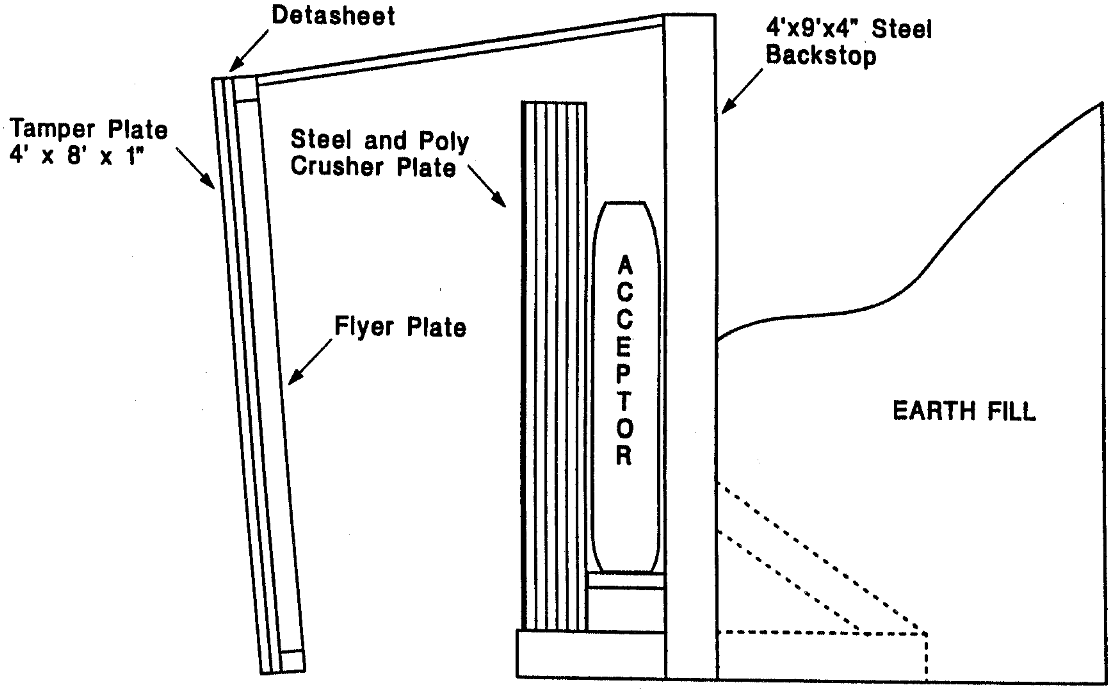

Figure 1. MK82 Bomb Flyer Plate Crush Test Setup

Figure 2. MK82 Bomb Flyer Plate Double Impact Test Setup

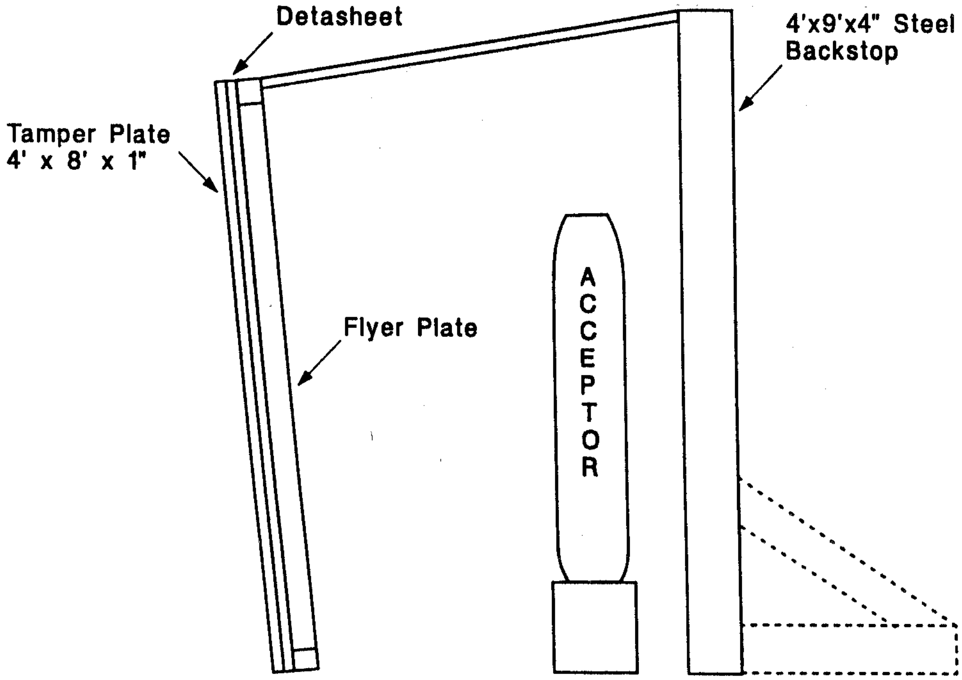

Figure 2. MK82 Bomb Flyer Plate Double Impact Test Setup

Figure 3. MK82 Bomb Deformation from Crush Test (Vfp = 141 m/s)

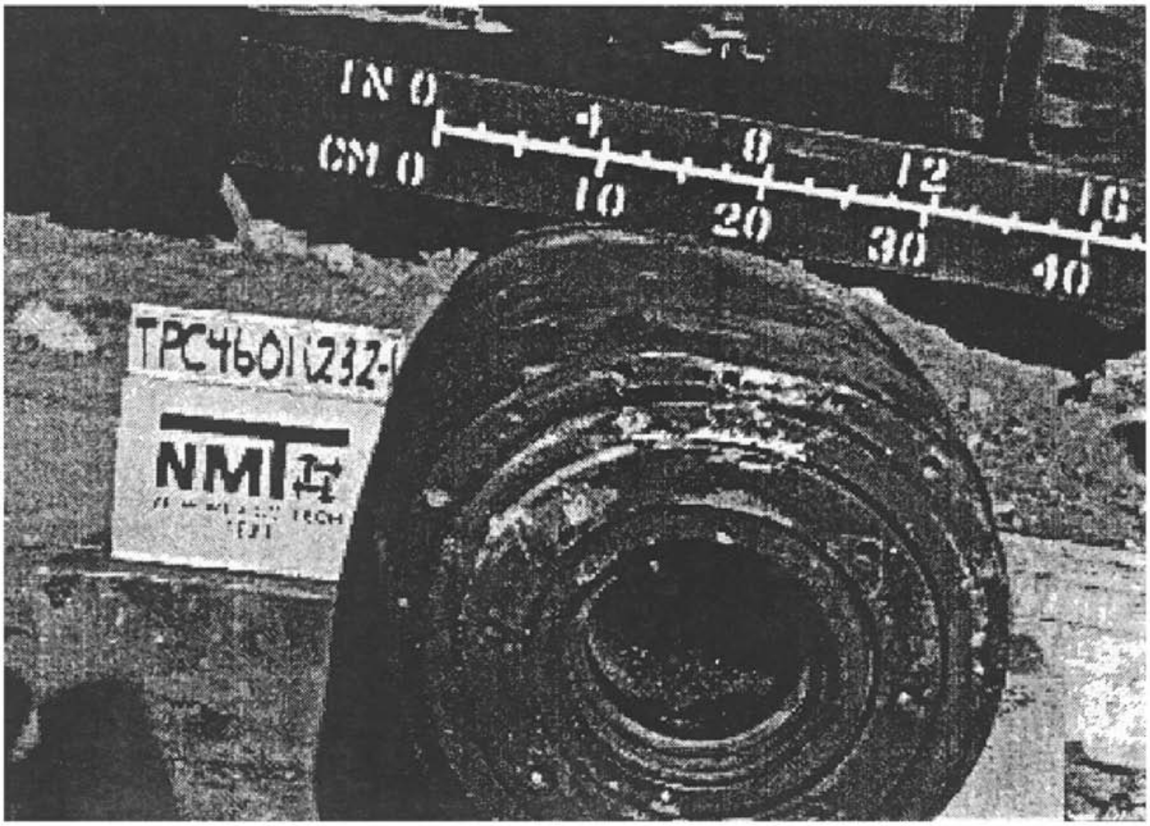

Figure 3. MK82 Bomb Deformation from Crush Test (V_{fp} = 141 m/s)

Figure 4. DYNA3D Crush Test Analysis Models

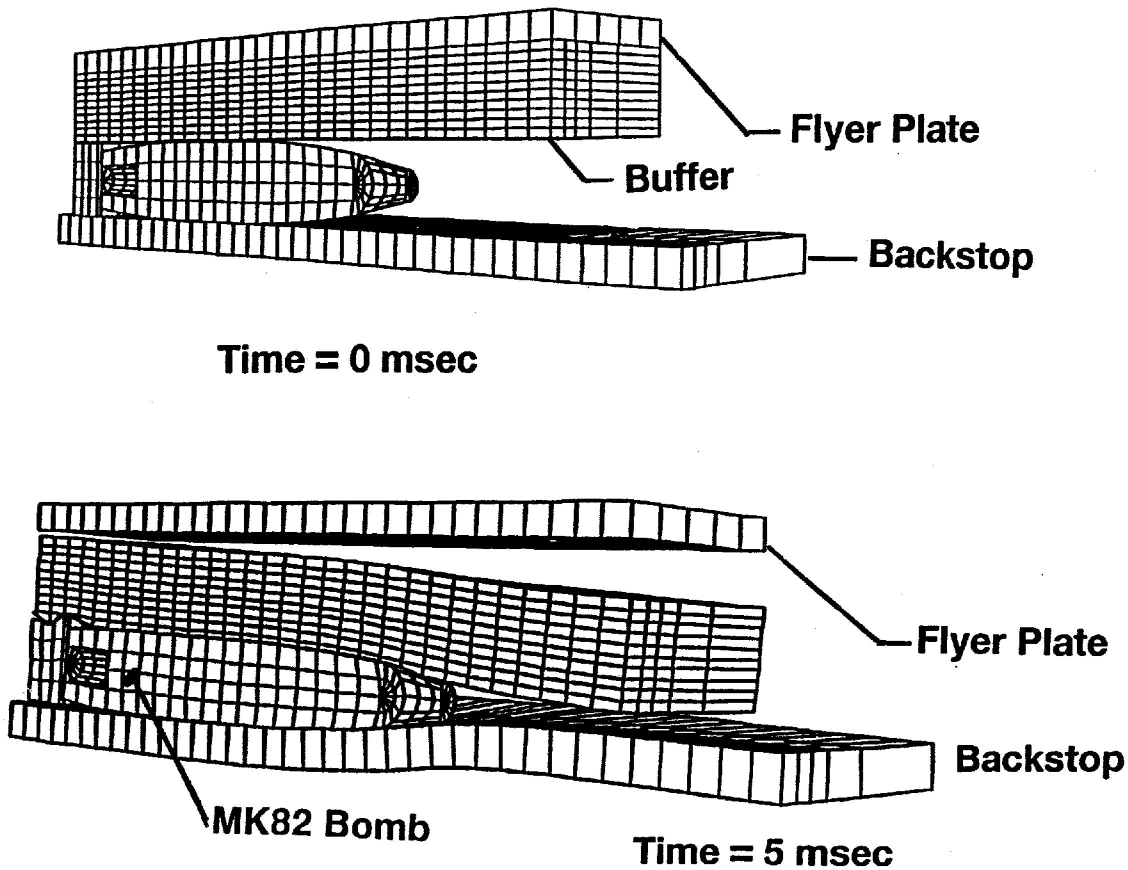

Figure 4. DYNA3D Crush Test Analysis Models

Figure 5. DYNA3D Predicted Principal Stress in Mk82 Bomb H-6 Explosive Fill (Vfp = 141 m/s)

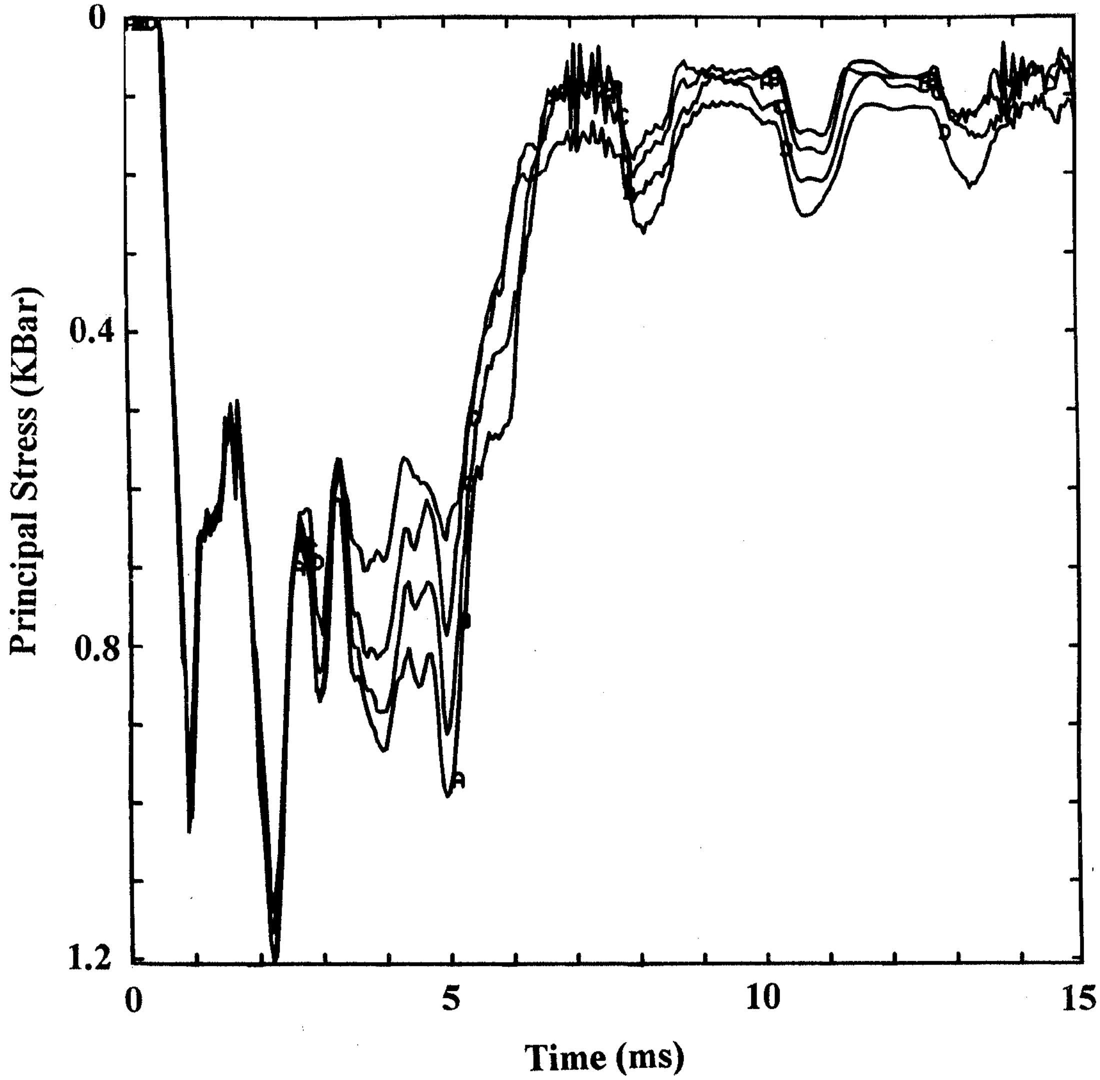

Figure 5. DYNA3D Predicted Principal Stress in Mk82 Bomb H-6 Explosive Fill (V_{fp} = 141 m/s)

Figure 6.
Peak Principal Stress vs. Flyer Plate Velocity (in MK82 H-6 Explosive Fill)

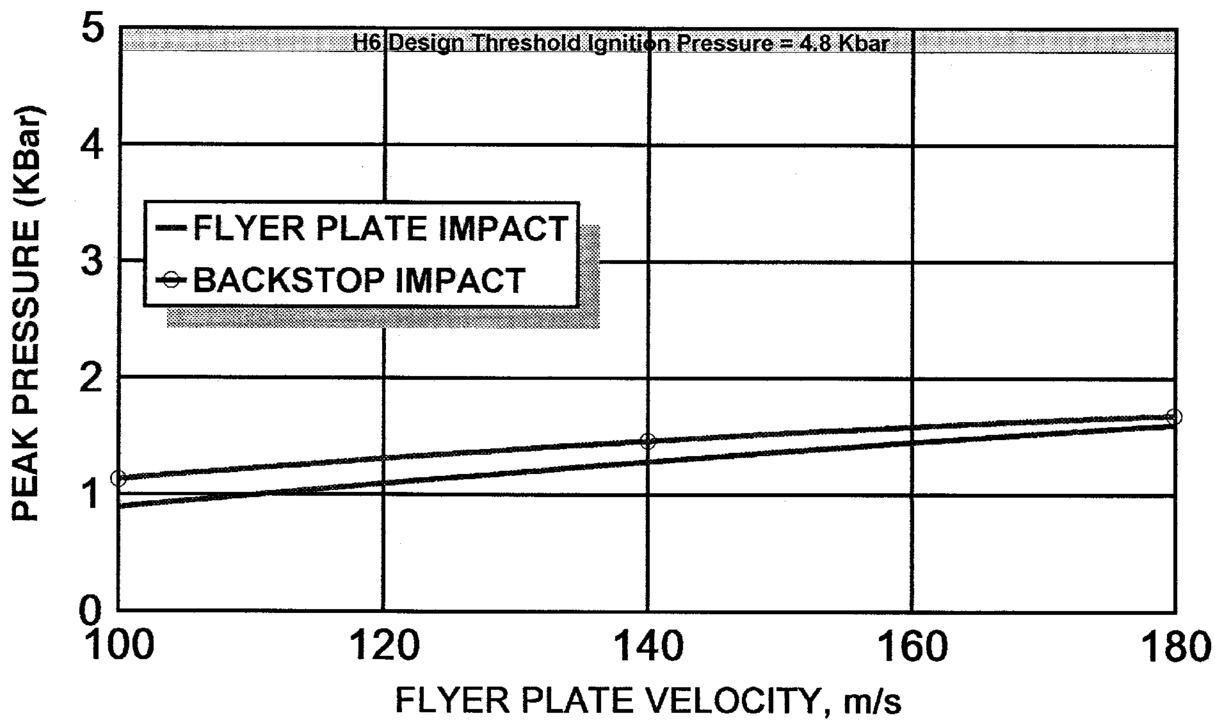

Figure 6. Peak Principal Stress vs. Flyer Plate Velocity
(in MK82 H-6 Explosive Fill)

Figure 7. Measured & Predicted MK82 Deformation

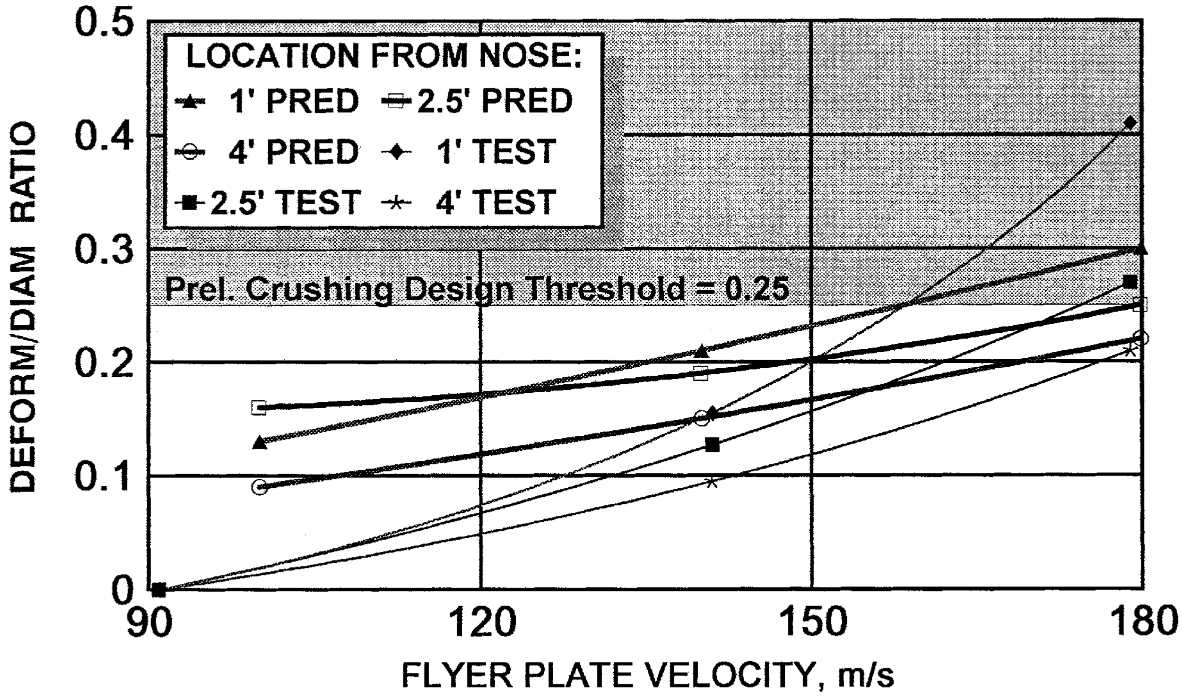

Figure 7. Measured & Predicted MK82 Deformation